Engineered Wood Products and Mass Timber Use in Wood Buildings

Daniel Hindman, Ph.D., P.E., Virginia Tech

Introduction

- Associate Professor in Department of Sustainable Biomaterials at Virginia Tech for 17 years
- Classes Include Design of Wood Structures, Timber Engineering, Green Building Systems, Wood Mechanics and BIM for Wood-Based Structures
- Research Areas Include Development of Cross-Laminated Timber from Alternative Species, Mechanical Properties of Engineered Wood Products, Connection Design of Engineered Wood Products

Disclaimer

- Discussion or inclusion of products in this presentation does not constitute an endorsement
- Products discussed serve as illustrations only
- Most products mentioned have several companies that produce similar or equivalent materials

Assumptions of Audience

- You should have a basic understanding of wood material properties
- You should be familiar with the *National Design Specification for Wood Construction* (NDS)
- You should be familiar with ASD and LRFD factors (these will not be discussed but do apply according to the NDS)
- You should be familiar with the way that design stresses of wood materials are modified (base design values are found in the *NDS Supplement*, then modified for the particular design situation)

Goals of Presentation

- Definition of EWPs
- Discussion of proprietary vs. nonproprietary materials and where to find design values
- Use of SCL and I-joists in taller wood construction along with detailing and connections
- An introduction to mass timber (Glulam & CLT) and how to design mass timber along with special considerations with CLT
- Frame and lateral systems with mass timber.

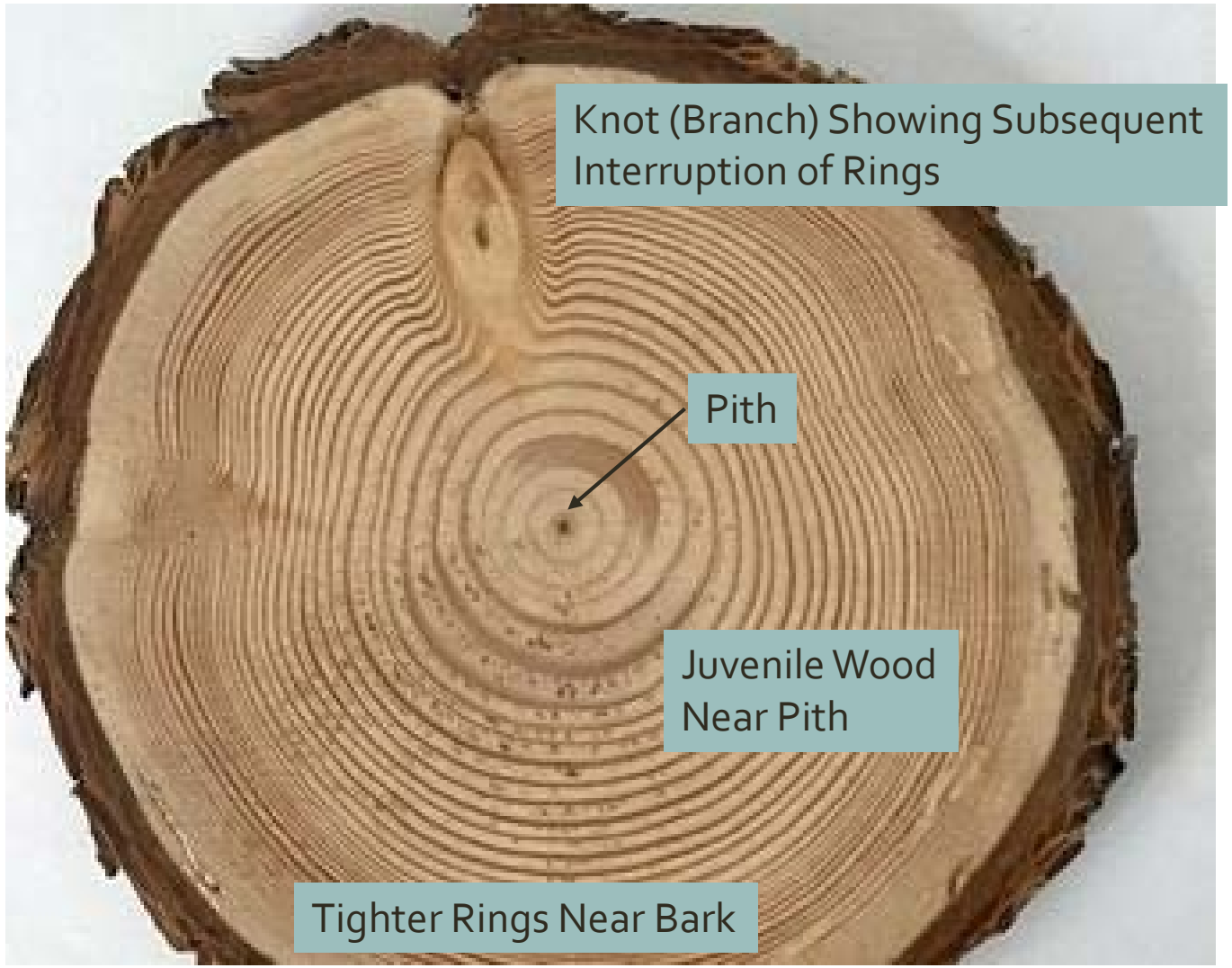
Schedule

- Define EWPs
- Why Use Wood Composites?
- Different Kinds of EWPs
- Proprietary vs. Non-Proprietary – Where Do We Find Properties?
- Plywood/OSB
- LVL / SCL
- I-joists
- Glulam
- CLTs / Mass Timber
- Design Methods
- Special Considerations
- Lateral Design of Mass Timber
- References and Where To Get More Information

Think About Wood Design

- Typically, our product of choice is solid-sawn, visually graded lumber
- Mechanical properties are listed in the *National Design Specification for Wood Construction* (NDS)
- NDS lists adjustment values (Load Duration, Wet Service, Temperature, Size, Buckling, Repetitive Member, etc.)
- Solid-sawn Visually Graded Lumber is a low-strength and variable product
- If we want to use wood materials in taller buildings (Over 6 Stories) and in different applications (Frame Structures, Mass Timber), we need to look at different materials

Anatomy of Large Timbers



2012 – Changes in Southern Pine Design Values Due to Presence of Juvenile Wood

New Design Values - Effective June 1, 2012

Released on: June 1, 2012

The Southern Pine Inspection Bureau (SPIB) issued new design values effective June 1, 2012 in*Supplement No.9 to the 2002 Standard Grading Rules for Southern Pine Lumber.* The ***only*** design values that changed apply to visually graded Southern Pine and Mixed Southern Pine sized 2" to 4" wide and 2" to 4" thick (2x2s through 4x4s) in No.2 and lower grades (No.2, No.3, Stud, Construction, Standard and Utility). This also includes new design values for No.2 Dense and No.2 NonDense Southern Pine. Design values for all other grades and sizes of visually graded Southern Pine remain the same, pending results of testing scheduled for completion later this year.

Many producers and key customer groups have already successfully transitioned to the new design values with minimal disruption to their businesses. Now that June 1 is here, Southern Pine users should begin using the new design values and revised span tables for new construction if they haven't done so already.

Building codes reference design values certified by the ALSC Board of Review. The American Wood Council (AWC) publishes these design values in a supplement to the code-referenced *National Design Specification® (NDS®) for Wood Construction*. Building codes also include span tables and other prescriptive requirements that need to be amended to reflect the new design values. Visit www.awc.orgto download the AWC *Addendum to Design Values for Wood Construction,* revised prescriptive span tables and other updates to AWC's standards and design tools. Also visit www.southernpine.com to obtain easy-to-use span tables for specific grades and sizes of Southern Pine lumber.

Limitations of Visually Graded Dimension Lumber

- Visually Graded Dimension Lumber is a Good Product for Low-Rise, Light-Frame Residential Construction
- There has been a decided push to use wood materials in taller structures for commercial, business and industrial uses
- For these larger structures, dimension lumber can be used
- However, there are design situations where the strength and stiffness of visually graded dimension lumber does not provide an effective material choice

Engineered Wood Products (EWPs)

- Engineered = Value-Added vs. Standard Lumber Item
- Typically we think of composites as value added
- Composites may be more expensive vs. replacing solid-sawn lumber
- Composites may be able to have greater capacity (carry higher loads, greater span distances, etc.) than solid-sawn lumber
- MSR (machine stress-rated) lumber is considered an EWP by some since the higher grading allows for premium pricing (not discussed here)

What's The Value of Wood Composites?

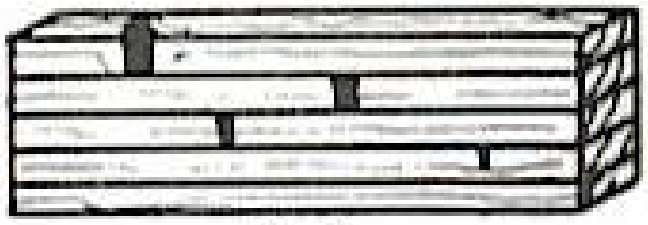
Composite Example – Solid Lumber

- Let's examine some lumber that's not the best pick of the bunch

- Spike Knot – this lumber doesn't seem too usable
- Mechanical properties will be low

Composite Example – Sawn Into Layers

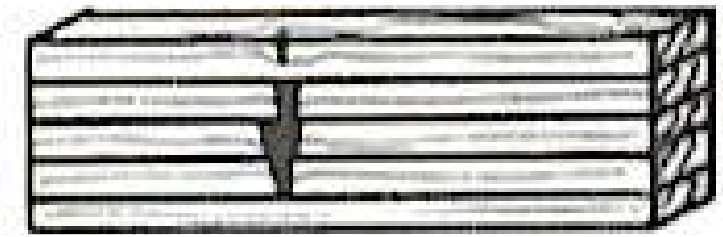
- What if we cut up the board and randomize the defects?



- The strength and stiffness of the board tends to increase.
- Why? Because the strength-reducing characteristic (knot) has been separated

Composites Example – Sawn Into Layers With Organization

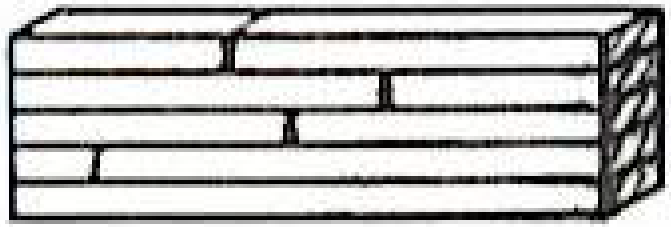
- What if we place the defects in the middle of the beam near the neutral axis?



- Strength and Stiffness Should Increase More For Bending
- Since high quality laminations are desired at the top and bottom of the beam, the interior laminations do not need to be as strong

Composites Example – Removal of Knot Portions

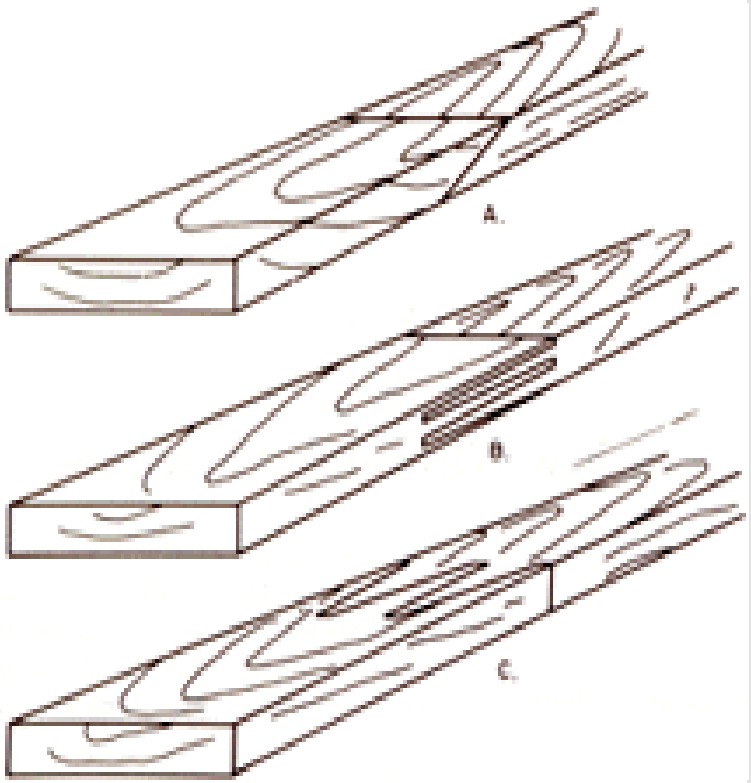
- Now, lets remove all defects and finger joint the clear lumber



- Strength and Stiffness Continue to Increase
- Essentially defect-free layers
- Important to stagger glue lines to prevent stress concentrations

What's a Finger Joint?

- Finger joints are used to increase the gluing area between a butt-jointed section of lumber
- Reduces the end grain contact
- Typically, finger joints are stronger than surrounding lumber



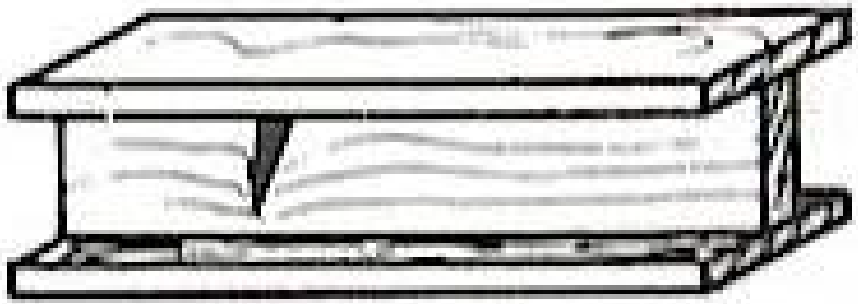
Composites Example – Strand Process

- What if we flake the entire piece of lumber?

- Flakes are sprayed with glue and bonded under heat and pressure
- Creates a uniform product
- Depending on manufacture, strength can be greater than original lumber

Composites Example – Changing The Shape

- What if we use the lumber as the web of an I-beam?



- Attaching higher quality wood products to the top and bottom can increase strength

Composites Example - Conclusion

- As we progressed through the different stages, we added **manufacturing time** and **cost** to our composite
- We need to balance the increase in strength / stiffness with cost to efficiently produce wood composites
- Some products will be noticeably stronger / stiffer than solid wood
- Many products will demonstrate increased stability as well

Engineered Wood Products

	Lumber-Based Materials	Veneer / Strand – Based Materials
Unidirectional Construction	Glulam (Glued Laminated Timber) NLT (Nail Laminated Timber)	LVL (Laminated Veneer Lumber), SCL (Structural Composite Lumber)
Cross-Layer Construction	CLT (Cross-Laminated Timber)	Plywood, OSB (Oriented Strandboard), MPP (Mass Plywood Panels)
Composite Construction	Wood Composite I-joists	

Groupings

- Light-Frame Building Products
  - Plywood / OSB
  - LVL, Other SCLs
  - Wood Composite I-joists
- Mass Timber
  - Glulam
  - LVL
  - NLT
  - CLT
  - MPP

Proprietary vs. Non-Proprietary

- Proprietary products are specific to a company
  - Companies hold the patents and are the sources for material properties / construction methods
- Non-proprietary products are manufactured to correspond to a certain grade or standard
  - The non-governmental organization (NGO) governing the grade or standard provides mechanical properties / construction methods

Proprietary vs. Non-Proprietary

- Proprietary Products
  - LVL, other SCLs
  - MPP
  - Wood Composite I-joists
  - DLT
- Non-Proprietary Products
  - Plywood / OSB
  - Glulam
  - NLT
  - CLTs?

Are CLTs Proprietary?

- Yes and No
- CLTs have a common grading system and a set of industry standards / mechanical properties set by ANSI/APA
- However, because there are few manufacturers, many grades are associated with manufacturers (i.e. Smartlam helped create a new grade for SPF(S) species group)
- Some manufacturers have specialized layups (Smartlam has a 4-layer CLT)

Finding Proprietary Product Data

- In order for building materials to be used in construction, the International Building Code specifies that:
  - An engineer must stamp plans indicating the properties or specific construction use
  - An independent evaluation service report (ESR) must be available for the product
- ICC Evaluation Service (www.icc-es.org)
- ESRs are free to access and search

Finding Non-Proprietary Product Information

- APA Website (www.apawood.org) is very comprehensive and has product information as well as general education / design methods
- Other trade association sources (AITC, TECO, etc) are also available
- Plywood/OSB Values – *Panel Design Specification* (APA) and NDS
- Glulam Values – Included in NDS
- NLT – Lumber properties in NDS, IBC provisions, specific design guide available
- CLT – *ANSI/APA PRG-320*

Light-Frame Product Descriptions

LVL - Description

- Veneer-based composite panel
- Typically all or most of the veneers are oriented in the machine direction (longitudinal)
- May be composed of multiple species of veneers according to manufacturer specifications
- Typical thickness is 1.75" thick
- Commonly used as beams, girders, headers

(https://www.archiexpo.com/prod/steico/product-59793-2164939.html)

(https://www.apawood.org/structural-composite-lumber)

SCL (Structural Composite Lumber)

- LVL is considered the most common SCL
- Other materials include strand-based products
- PSL is used similar to LVL, but is also manufactured in approx. 12” x 20” billets
- LSL is typically 1.75” thick
- Used as girders, columns, headers, replacements for lumber (LSL)

(https://www.weyerhaeuser.com/woodproducts/engineered-lumber/parallam-psl/parallam-psl-columns/)

(https://shepleywood.com/laminated-strand-lumber-gives-you-a-solidstart/)

Parallam – Accepts Pressure Preservative Treatment (PPT)

Features and Use Characteristics for Parallam® Plus PSL Beams, Headers, and Columns

Feature/Use Characteristics	WOLMANIZED® OUTDOOR® WOOD	WOLMANIZED® HEAVY DUTY™ WOOD
	Beams and Headers	Columns
AWPA Use Category	UC4A or lower	UC4B or lower
Saltwater Splash Permitted	No	Yes
Treatment	Copper Azole	CCA
Kiln Dried After Treating	Yes (KD 19)	Yes (KD 19)
Decay Protection	Yes	Yes
Termite Protection	Yes	Yes
Corrosion-Resistant Hardware Required	Yes	Yes
Suitable for Interior Applications	Yes	Yes
Paintable or Stainable	Yes	Yes

Specifying SCLs – Design Properties and Span Tables (PSL – Weyerhaeuser)

DESIGN PROPERTIES

Allowable Design Stresses for Beams and Columns (100% Load Duration)

Service Level	G Shear Modulus of Elasticity (psi)	E Modulus of Elasticity (psi)	E_{min} Adjusted Modulus of Elasticity (psi)	F_b Flexural Stress(1) (psi)	F_t Tension Stress(2) (psi)	$F_{c\perp}$ Compression Perpendicular to Grain(3) (psi)	$F_{c\parallel}$ Compression Parallel to Grain (psi)	F_v Horizontal Shear Parallel to Grain (psi)	C_{RP} Creep Factor	SG Equivalent Specific Gravity
Beam(4) Application										
1	103,750	1.660×10^6	843,725(5)	2,117	1,519	533	2,030	241	0.20	0.50
2	91,250	1.460×10^6	742,070(5)	1,827	1,397	368	1,508	197	0.60	0.50
3	83,750	1.340×10^6	681,080(5)	1,624	1,337	263	1,189	171	0.85	0.50
Column Application										
1	93,375	1.494×10^6	759,350(6)	1,752(7)	1,316	215(7)	1,750	160(7)	0.20	0.50
2	82,125	1.314×10^6	667,865(6)	1,512(7)	1,211	150(7)	1,300	120(7)	0.60	0.50
3	75,375	1.206×10^6	612,970(6)	1,344(7)	1,158	110(7)	1,025	100(7)	0.85	0.50

Floor Load (PLF)—Service Level 2

Load Duration	Span	Condition	3½" Width				5¼" Width			
			9¼"	11⅞"	14"	16"	9¼"	11⅞"	14"	16"
100% Floor	8'	Total Load	966	1,347	1,427	1,427	1,449	2,021	2,140	2,140
		Live Load L/360	853	*	*	*	1,280	*	*	*
		Min. End/Int. Bearing (in.)	3.0/7.6	4.2/10.6	4.5/11.3	4.5/11.3	3.0/7.6	4.2/10.6	4.5/11.3	4.5/11.3
	10'	Total Load	546	988	1,137	1,137	819	1,482	1,706	1,706
		Live Load L/360	458	918	*	*	686	1,377	*	*
		Min. End/Int. Bearing (in.)	2.2/5.4	3.9/9.8	4.5/11.3	4.5/11.3	2.2/5.4	3.9/9.8	4.5/11.3	4.5/11.3
	12'	Total Load	320	660	933	944	479	990	1,399	1,417
		Live Load L/360	272	554	875	*	408	830	1,312	*
		Min. End/Int. Bearing (in.)	1.6/3.9	3.2/7.9	4.4/11.1	4.5/11.3	1.5/3.9	3.2/7.9	4.4/11.1	4.5/11.3
	14'	Total Load	200	421	677	807	300	631	1,016	1,210
		Live Load L/360	174	358	570	*	261	536	855	*
		Min. End/Int. Bearing (in.)	1.5/3.5	2.4/5.9	3.8/9.5	4.5/11.3	1.5/3.5	2.4/5.9	3.8/9.5	4.5/11.3
	16'	Total Load	132	282	459	668	198	423	688	1,002
		Live Load L/360	118	244	391	570	177	365	586	855
		Min. End/Int. Bearing (in.)	1.5/3.5	1.9/4.6	3.0/7.4	4.3/10.7	1.5/3.5	1.9/4.6	3.0/7.4	4.3/10.7
		Total Load	90	196	322	478	135	294	483	717

LVL and SCLs In The NDS (Chapter 8)

- Applicable Factors
  - Wet Service
  - Temperature
  - Beam Stability
  - Volume Factor
  - Repetitive Member Factor
  - Column Stability
  - Bearing Area Factor
- Wet Service Use is specified by manufacturers
- Volume Factor is obtained from product literature, should not be used in combination with Beam Stability Factor
- Repetitive Member Factor is $C_r = 1.04$, rather than 1.15 for solid-sawn lumber

Splitting of LVL / Aligned Composites From Perpendicular-to-Grain Loading

- The directional alignment of veneers in LVL can lead to an increased chance of splitting
- From studies by Hindman et al. (2010) and Patel and Hindman (2012), design values in *TR-12 General Dowel Equations for Calculating Lateral Connection Values* can be used to predict the performance of LVL

Hindman, D. P., D. E. Finkenbinder, J. R. Loferski, and P. Line. 2010. Strength of Sawn Lumber and Wood Composite Dowel Connections Loaded Perpendicular to grain: NDS Design Equations. Journal of Materials in Civil Engineering. 22(12): 1226-1234.

Hindman, D. P., M. Patel. 2012. Comparison of Single and Two-Bolted LVL Perpendicular-to-Grain Connections. I: National Design Specification for Wood Construction Equations. Journal of Materials in Civil Engineering. 24(4) : 9 p.

Plywood and Oriented Strandboard (OSB)

- Plywood – based on veneers
- OSB – based on strands
- Layers Orthogonal (90 degrees) to Each Other
- Typically odd number of layers
- Standards for Production
  - PS-1 - Plywood
  - PS-2 – OSB, other fiber-based panels
- Used for sheathing of floors and walls
- High shear value provide resistance for shearwall and diaphragm construction

(https://www.prosalesmagazine.com/products/lumber/plywood-vs-osb-which-is-better_o)

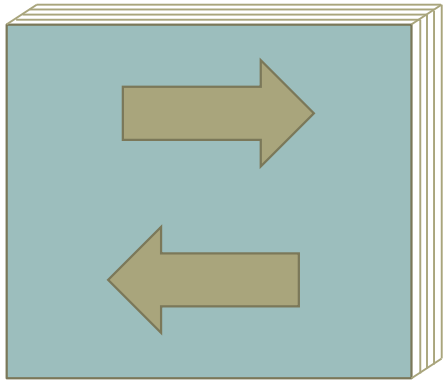
Structural Plywood

$\neq$

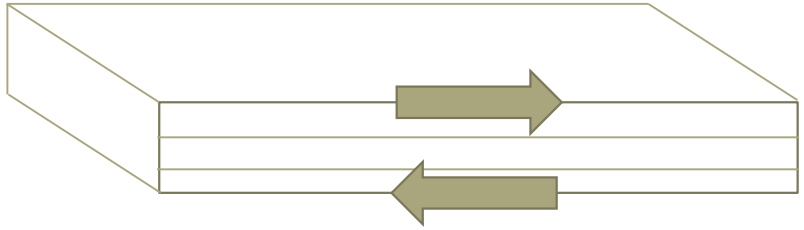
Decorative Plywood

Plywood / OSB In The NDS (Chapter 9)

- Properties are given as composite values (size cannot be separated from strength/stiffness term)
  - F_bS instead of F_b
  - Note F_bS = Moment
- Two types of shear strength are provided
  - F_vt_v = horizontal shear
  - $F_s(Ib/Q)$ = rolling shear



Horizontal Shear



Rolling Shear

Plywood/OSB in the NDS (Chapter 9)

- Applicable Factors
  - Wet Service
  - Temperature
  - Panel Size
- Wet Service and Temperature are defined in manufacturer / trade literature
- Panel Size Factor
  - If panel with is less than or equal to 8 inches, $C_s = 0.5$
  - If panel width is greater than 8 inches or less than 24 inches, $C_s = (8+\text{panel width})/32$
  - If panel width is 24 inches or greater, $C_s = 1.0$

Plywood/OSB In the NDS (SDPWS)

- The main use for plywood/OSB panels is as diaphragms and shearwall elements
- This discussion is included in the Special Design Provisions for Wind and Seismic (SDPWS) document (Included in NDS packet)
  - Allowable loads for different spans of panel applied over joists (direct wind pressure)
  - Unit shear values for various constructions of diaphragms and shearwalls provided
  - Diaphragm and shearwall deflection equations
  - Values for shear modulus (G_s) of panels for use in diaphragm and shearwall deflection
  - Various construction details, especially for high wind and seismic conditions provided

Moisture and Plywood/OSB

- You have probably heard over and over that moisture is bad for wood products (expansion, mold/fungal growth, loss of strength)
- Moisture on construction sites happens (rain, snow)
- ***It is important to make sure that a building is dry before it is enclosed***
- "Enhanced OSB" products have been introduced that advertise greater moisture resistance
  - Products use more wax and resin which ***slows the moisture movement*** (into and out of product)
- I have heard anecdotes from flooring inspectors of moisture-related flooring problems attributed to Enhanced OSB products
- Once more, ***It is important to make sure that a building is dry before it is enclosed no matter what sheathing is used!***

Wood Composite I-joists

- Composite shape consisting of solid wood / LVL flanges and plywood / OSB web
- Only used for floor and roof joists
- Very lightweight but strong under <u>correctly applied load</u>
- Different sizes than solid-sawn lumber to present mixing
- Uses SCL or Engineered Wood Rimboard Products as well

(https://www.apawood.org/i-joist)

(https://www.menards.com/main/building-materials/trusses-i-joists-engineered-lumber/c-5657.htm)

Wood Composite I-joists in the NDS (Chapter 7)

- Properties are given as composite values
  - M_r, V_r, R_r, EI, EI_{min}, K
  - K = Shear stiffness coefficient for Wood I-joists. See Manufacturer's literature for adjustment of bending stiffness to include shear deflection
- Adjustment Factors
  - Wet Service
  - Temperature
  - Beam Stability
    - For unsupported joists, treat compression flange only as a column continuously braced in the direction of the web and calculate a corresponding C_P value for use as C_L
    - Given the small size of the flange, buckling loads are very small!
  - Repetitive Member – Repetitive Member Factor C_r = 1.0

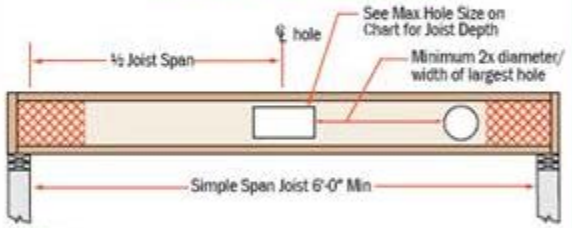
I-joists – With Great Power Comes Great Responsibility

- Many I-joists come with pre-punched 1” holes in the web
- Larger holes can be cut, but . .
- **YOU MUST PAY CLOSE ATTENTION TO SPECIFIC MANUFACTURER GUIDELINES**
- Manufacturer guidelines differ, even to the methods used for measuring the placement of holes and the type of holes (round/square)

Large Rectangular Holes in BCI® Joists

Hole size table based on maximum uniform load of 40 psf live load and 10 psf dead load, at maximum spacing of 24" on-center.

Single Span Joist

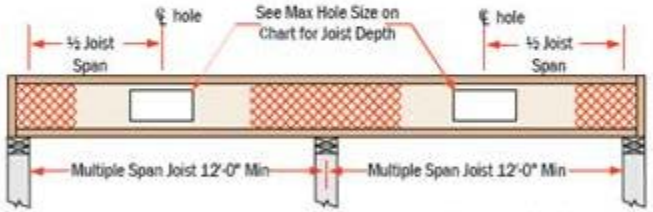


Notes:

Additional holes may be cut in the web provided they meet the specifications as shown in the hole distance chart shown above or as allowed using BC CALC® sizing software.

Joist Depth	Maximum Hole Size	
	Simple Span	Multiple Span
9½"	6" x 14"	6" x 12"
11⅞"	7" x 16" 8" x 15"	8" x 12"
14"	9" x 16" 10" x 15"	8" x 15"
16"	9" x 18" 11" x 16"	10" x 14"

Multiple Span Joist



Larger holes may be possible for either Single or Multiple span joists; use BC CALC® sizing software for specific analysis.

Boise Cascade EWP • Eastern Specifier Guide • 08/04/2015 r 04/01/2019

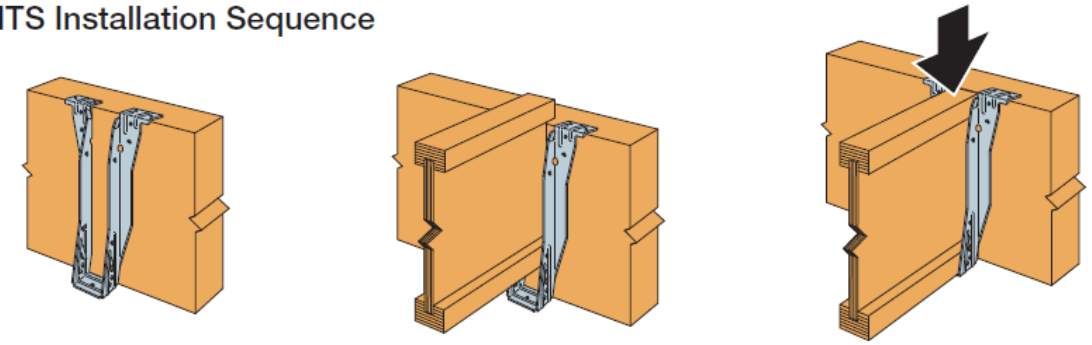
(https://bc.ewpsupport.com/hc/en-us/articles/360025846672-Eastern-Specifier-Guide-has-Updated-Table-for-Large-Rectangular-Holes-in-BCI-Joists)

Putting a Toilet In The Wrong Place . . .

- Locating a toilet directly over an I-joist is a BIG problem
- If you miscut or over-cut a hole in an I-joist, you must have an engineered solution
- Many of the I-joist manufacturing companies offer technical support and are willing to help you with retrofitting problems
- Other engineered solutions may also be available

I-joists – Specialized Connections

ITS Installation Sequence

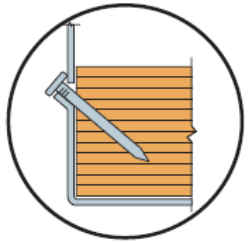


Step 1
Attach the ITS to the header.

Step 2
Slide the I-joist downward into the ITS until it rests above the Strong-Grip™ seat.

Step 3
Firmly push or snap I-joist fully into the seat of the ITS.

Positive-Angle Nailing



Correct Nailing
Approx. 45° angle

ITS Series with Various Header Applications

Model	Fasteners (in.)			Allowable Loads Header Type								Code Ref.
	Top	Face	Joist	Uplift (160)	LVL	PSL	LSL	DF/SP	SPF/HF	DF/SCL I-Joist	SPF/HF I-Joist	
ITS Series (Standard Installation)	(4) 0.148 x 1½	(2) 0.148 x 1½	—	120	1,395	1,245	1,625	1,455	1,140	1,085	940	—
	(4) 0.148 x 3	(2) 0.148 x 3	—	120	1,550	1,365	1,780	1,470	1,150	—	—	IBC, FL, LA
	(4) 0.162 x 3½	(2) 0.162 x 3½	—	120	1,785	1,735	1,905	1,565	1,225	—	—	
ITS Series (Alternate Installation)	(4) 0.148 x 3	(4) 0.148 x 3	—	120	1,735	1,595	1,885	1,955	1,230	—	—	—
	(4) 0.162 x 3½	(4) 0.162 x 3½	—	120	1,785	1,735	1,905	1,955	1,490	—	—	
	(4) 0.148 x 3	(4) 0.148 x 3	(4) 0.148 x 1½	630	1,735	1,595	1,885	1,955	1,230	—	—	
	(4) 0.162 x 3½	(4) 0.162 x 3½	(4) 0.148 x 1½	630	1,785	1,735	1,905	1,955	1,490	—	—	
MIT Series	(4) 0.148 x 1½	(4) 0.148 x 1½	(2) 0.148 x 1½	215	2,035	1,500	1,605	2,275	1,115	1,230	885	IBC, FL, LA
	(4) 0.148 x 3	(4) 0.148 x 3	(2) 0.148 x 1½	215	2,335	2,000	1,605	2,570	1,665	—	—	
	(4) 0.162 x 3½	(4) 0.162 x 3½	(2) 0.148 x 1½	215	2,550	2,140	2,115	2,575	1,665	—	—	
HIT Series	(4) 0.162 x 3½	(6) 0.162 x 3½	(2) 0.148 x 1½	315	2,550	2,220	2,500	2,875	2,000	—	—	

(Simpson Strong Tie Catalog C-C-2019, p.160)

I-joist Jobsite Safety

- "Very lightweight but strong under correctly applied load"
- Wood I-joists are only meant to be used in combination with sheathing
- Joists have little strength in off-axis bending and torsion
- Lateral torsional buckling of wood I-joists is a problem
- LTB can be induced by workers walking on I-joists!
- We conducted research on workers walking on I-joists in a controlled environment **(Please Don't Try At Home/Work!)**

Introduction To Mass Timber

Design Philosophy

- Light Frame Philosophy
  - "Do More With Less"
  - Create a strong, efficient structure using a minimal amount of wood
  - Provides room for insulation in cavities
  - More focus on prescriptive design (focus on 1-3 story structures, up to 6 stories allowed)
- Mass Timber Philosophy
  - Using Larger Sections of Wood Elements To Carry More Load
  - Goal is creating larger structures
  - Currently, the IBC allows up to 18 stories
  - Competitive product to concrete/steel frames

Let's Make Big Buildings!

- Michael Green, MG Architecture
- 2010 TED-TALK "Why We Should Build Wooden Skyscrapers"
- 2012 White Paper "The Case for Tall Wood Buildings"
- Excited people about using mass timber and helped them realize what could be done with wood

(https://www.ted.com/talks/michael_green_why_we_should_build_wooden_skyscrapers)

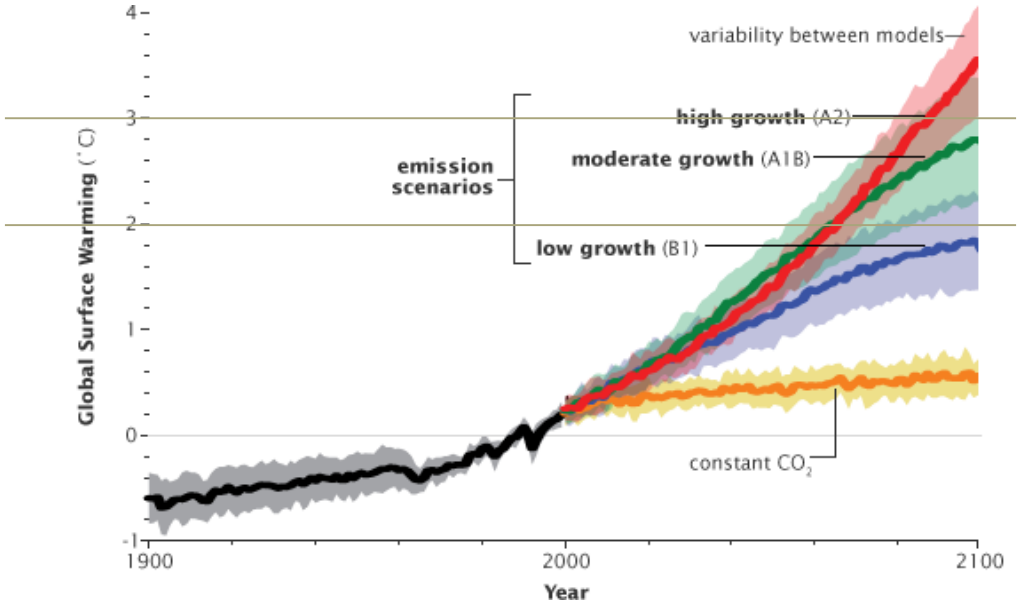
Replacing Steel and Concrete

- CLT can be thought of as a "fuzzy" pre-cast concrete panel
- CLT manufacturing plants are coupled with CNC operations to cut panels to exact size for installation
  - Intent = No cutting of CLT occurs on the jobsite!
- ***CLT is a two-way building element that wood design was missing previously***
- ***This is the "special ingredient" that has helped develop the field of mass timber***
- *CLT (and MPP) = Concrete*
- *Glulam, LVL = Steel*
- *Other materials such as NLT and DLT act as one-way slabs*

(Hindman)

Sustainability

- CLT and Mass Timber can be thought of as carbon storage devices, able to lock away carbon dioxide from re-entering the atmosphere
- Trees and plants are still the most effective and economical way to remove carbon from the atmosphere
- By building with wood, this carbon is sequestered and used for our benefit



Advantages of Mass Timber

- Shorter Construction Time
- Lighter Weight
- Panels are Pre-cut for Window and Door Openings
- Smaller Crew Size Needed (Crane)
- Long Screws (Selfdrilling) Used for Attachment
- "Pull" Market – Architects and Engineers Asking for CLTs

Disadvantages of Mass Timber

- Availability
- Building Code Acceptance
  - Heights and Area Limitations on Wood Construction
  - Based on Fire Tests
  - Perceptions about CLTs and Fire
- Difficult to make (Specialized Facility)

Moisture in Mass Timber

- As moisture content increases and decreases, wood will expand and shrink
- This is true in mass timber as well as other forms of construction
- Because mass timber has larger wood elements, it may experience more swelling/shrinkage overall
- Timber Design Guide 2019-18 "Moisture Considerations for Mass Timber Structures" by Jim DeStefano, TFEC
- DeStefano recommends that structures be designed for an 8% moisture content change between construction and use
- Be aware of joints and connections which may open or spread due to these changes in moisture content

Product Descriptions for Mass Timber

Glulam

- A series of 2x material planed and glued with structural adhesive to form beams and columns
- Construction usually consists of clamping members with glue applied to a rigid backstop – could be straight, curved or tapered
- Can be optimized for bending (i.e. higher quality laminations on top and bottom, lower quality laminations in center)
- Originally, oversight provided by AITC, American Institute of Timber Construction
- Now has been incorporated into APA

Glulam in the NDS (Chapter 5)

- Mechanical Properties of Glulam Included in Chapter 5 of the NDS Supplement
- Chapter 5 of the NDS (main book) provides more design details
- Additional Strength Term – F_{rt} radial tension strength perpendicular to grain
  - Section 5.2.8 detail how to determine F_{rt} based upon species and loading

- Adjustment Factors
  - Wet Service
  - Temperature
  - Beam Stability
  - Volume
  - Flat Use
  - Curvature
  - Stress Interaction
  - Shear Reduction
  - Column Stability
  - Bearing Area

Glulam in the NDS (Chapter 5)

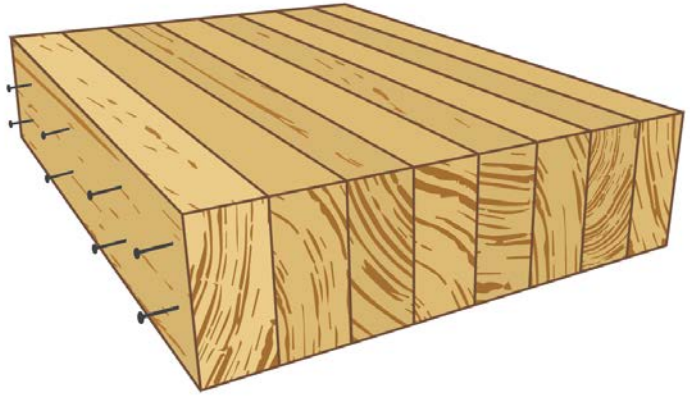
- The adjustment factors just mentioned speak to what can be produced with glulam vs. solid-sawn lumber
- Volume Factor: Instead of a size factor, glulam uses a volume term to adjust for different sizes
  - Base size = 5.125″ x 12″ x 21″ member
  - Smaller sizes do not receive an adjustment
  - Not applied simultaneously with Beam Stability factor
- Curvature Factor
  - The creation of curved glulam members introduces an increase in bending strength
  - t/R ratio = lamination thickness (in) / Radius of curvature (in)
  - For hardwoods and Southern Pine, $t/R \leq 1/100$
  - For other softwoods, $t/R \leq 125$

Glulam in the NDS (Chapter 5)

- Stress Interaction Factor, C_I
  - Stress Interaction terms apply to tapered members
  - Taper on Compression Face – Interaction with shear and compression perpendicular to grain
  - Taper on Tension Face – Interaction with shear and radial tension perpendicular to grain
  - Stress Interaction is not applied simultaneously with Beam Stability factor
- Shear Reduction Factor, C_{vr}
  - C_{vr} = 0.72 for any of the following cases
  - Design of non-prismatic members
  - Design of members subject to impact or repetitive cyclic loads
  - Design of members with notches
  - Design of members at connections

NLT (Nail Laminated Timber)

- Solid wood panel of lumber nailed together
- "One Way" Panel With Strength in Main Direction
- Panel Does Require Additional Support In Cross-Direction
- Mostly used for floors / roofs, but can be used for walls



(https://www.naturallywood.com/products/what-is-nail-laminated-timber/)

(https://structurecraft.com/materials/mass-timber/cross-laminated-timber)

NLT

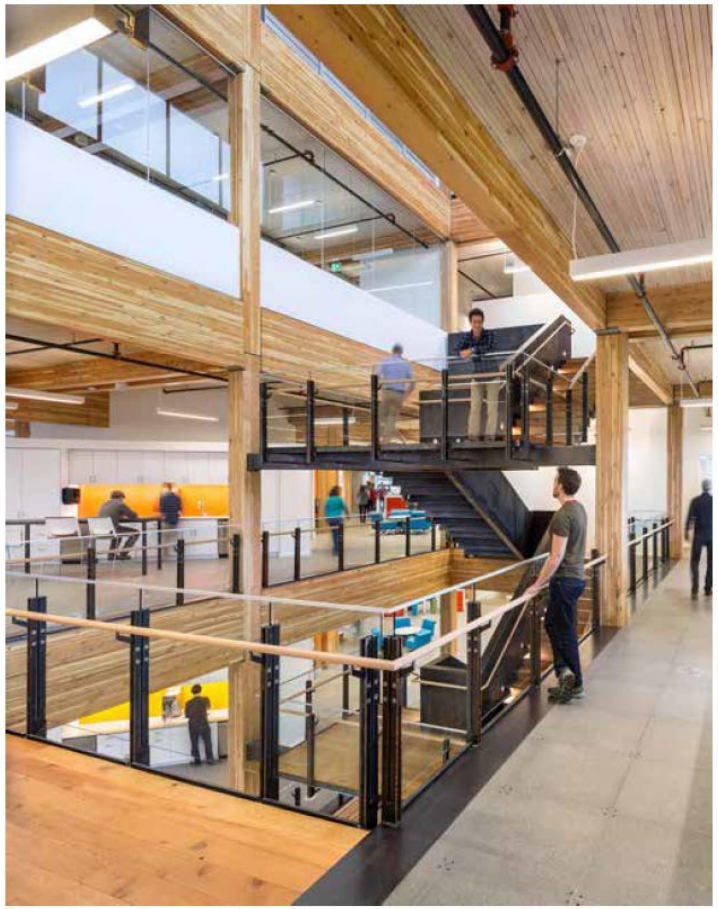


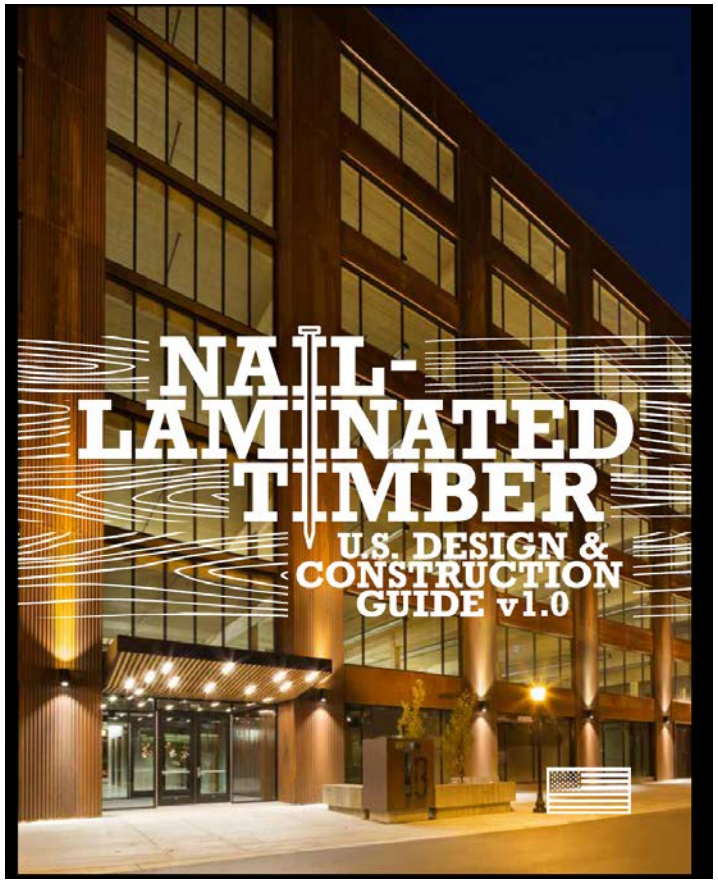
Figure 2.10: *Uniform Depth Cross Section.*

Figure 2.11: *1:1 Alternating Staggered Depth Cross Section.*

Figure 2.12: *2:1 Alternating Staggered Depth Cross Section.*

NLT Source Material

- "Nail Laminated Timber Design and Construction Guide"
  - Available from ThinkWood
- International Building Code
- NDS



Designing NLT Is Like Designing With Solid-Sawn Lumber

- An NLT acts like lumber stacked together (1.5" spacing)
- The terms F_b', F_v' and E' are determined according to solid-sawn lumber provisions in the NDS
  - Usually Beam Stability factor $C_L = 1.0$ unless near a large opening or narrow section of NLT
  - Size factor C_F depends on size of individual laminations
  - Repetitive Member factor C_r of 1.15 is applied to NLT
- However, there are some additional terms to account for:
  - Layup of interior joints and support locations
  - Staggered assemblies

Lamination Nailing

- Lamination nailing provides vertical shear transfer, maintains continuity of product and pulls laminations together
- Nails are 10d Common galvanized
- Additional nails may be needed for panel-to-panel connections

TABLE 4.6 MINIMUM LAMINATION NAILING

NLT TYPE	NLT DEPTH (NOMINAL)	NAILING PATTERN	
		3 in. long, 0.148 in. diameter nails (staggered)	3 in. long, 0.128 in. diameter nails (staggered)
Continuous Laminations	Less than 6 in.	One row @ 7 in. o.c.	One row @ 5 in. o.c.
	More than 6 in.	Two rows @ 14 in. o.c.	Two rows @ 10 in. o.c.
Butt-Jointed Laminations*	Less than 6 in.	One row @ 7 in. o.c.	One row @ 5 in. o.c.
	More than 6 in.	Two rows @ 10 in. o.c.	Two rows @ 10 in. o.c.

Note: *Nails are smooth shank galvanized steel nails.*

**Provide two additional nails on each side of every butt joint.*

Design Equations

- K_{layup} factor accounts for differences in how the individual lumber is connected together over the supports
- $K_{section}$ is for NLT layups that have a staggered cross-section (i.e. alternating 2x6 and 2x4). For a constant thickness cross-section, $K_{section} = 1.0$

$$F'_{b-NLT} = F'_b * K_{layup,b} K_{section,b}$$

$$F'_{v-NLT} = F'_v * K_{section,v}$$

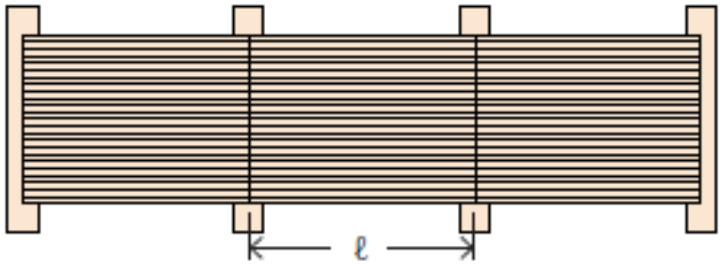
$$EI = E'_{NLT} I = E' * K_{layup,E} * K_{section,E} \frac{b_{panel} d^3}{12}$$

K_{layup} Common Configurations

- Case 1: Laminations continuous and simple span

$K_{layup,b} = 1.0$ $\quad$ $K_{layup,E} = 1.0$

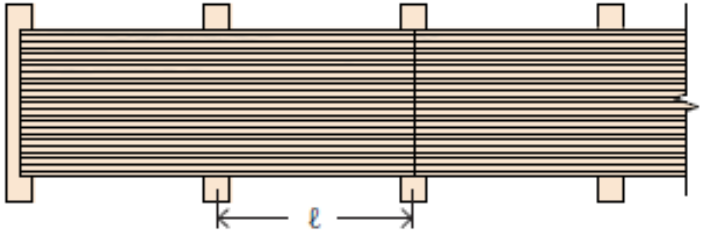
$$M = \frac{wL^2}{8} \qquad \Delta = \frac{5wL^4}{384E(d^3/12)}$$



- Case 2: Laminations continuous and multiple span

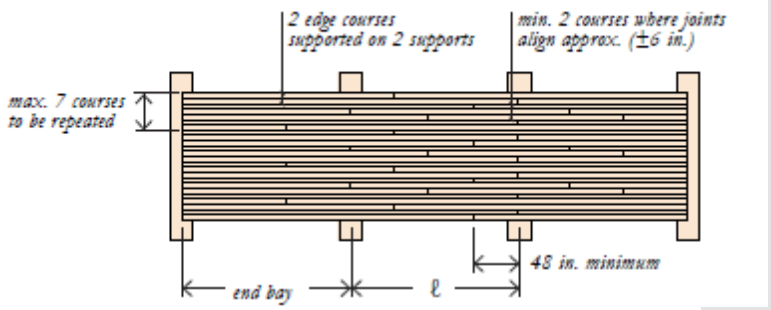
$K_{layup,b} = 1.0$ $\quad$ $K_{layup,E} = 1.0$

$$M = \frac{wL^2}{8} \qquad \Delta = \frac{wL^4}{185E(d^3/12)}$$



K_{layup} Common Configurations

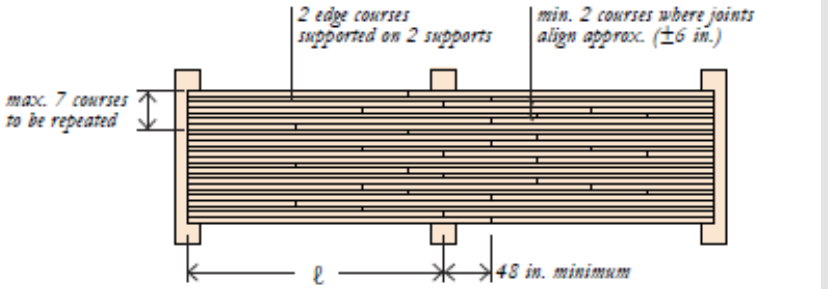
- Case 3: Laminations with controlled random butt joints over 4 or more supports



$$K_{layup,b} = 0.67 \qquad K_{layup,E} = 0.69$$

$$M = 0.10wL^2 \qquad \Delta = \frac{0.0069wL^4}{E(d^3/12)}$$

- Case 4: Laminations with controlled random butt joints over fewer than 4 supports



$$K_{layup,b} = 0.0202\frac{(L/d)^{1/4}}{s^{1/9}} \qquad K_{layup,E} = 0.0436\frac{(L/d)^{9/10}}{s^{1/5}}$$

$$M = \frac{wL^2}{8}$$

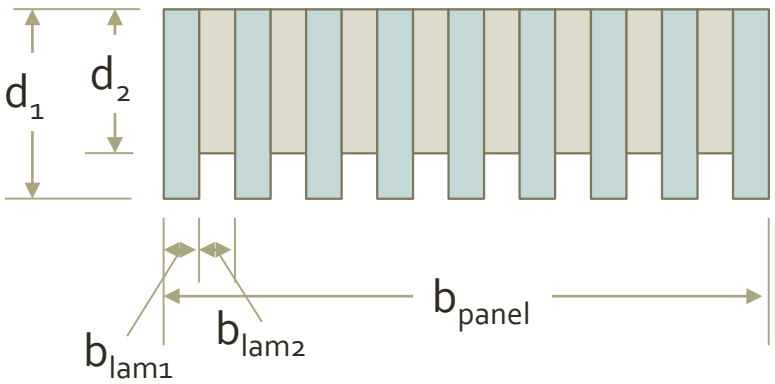
Single Span

$$\Delta = \frac{5wL^4}{384E(d^3/12)}$$

Double Span

$$\Delta = \frac{wL^4}{185E(d^3/12)}$$

$K_{section}$ Equations



$$X_1 = \frac{\sum b_{lam1}}{b_{panel}}$$

$$X_2 = \frac{\sum b_{lam2}}{b_{panel}}$$

$$K_{section,b} = X_1 + X_2 \left[\frac{d_2}{d_1}\right]^3$$

$$K_{section,v} = X_1$$

$$K_{section,E} = X_1 + X_2 \left[\frac{d_2}{d_1}\right]^3$$

NLT Used As Wall Section

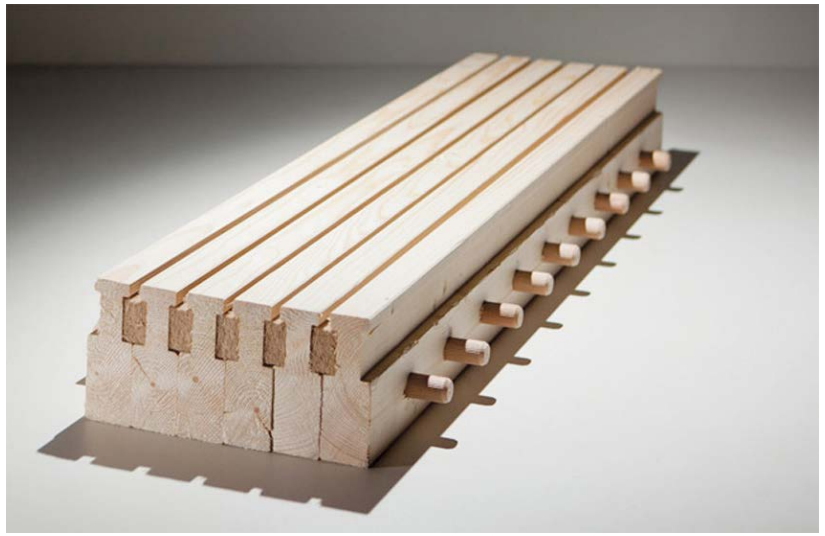
- For use as wall section, consider lumber elements spaced 1.5 inches on center
- Be sure to check Column Stability factor C_P for minor axis (i.e. panel thickness) dimension. The NLT is considered reinforced in the major direction.

Lateral Design of NLT (Diaphragms and Shearwalls)

- NLT products themselves cannot be used as diaphragms and shearwalls
- Must be sheathed with appropriate structural panels and nailed according to the *Special Design Provisions for Wind and Seismic* (SDPWS)

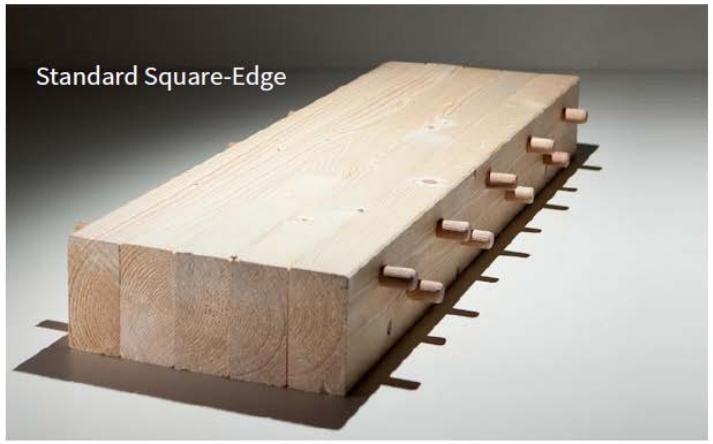
DLT (Dowel Laminated Timber)

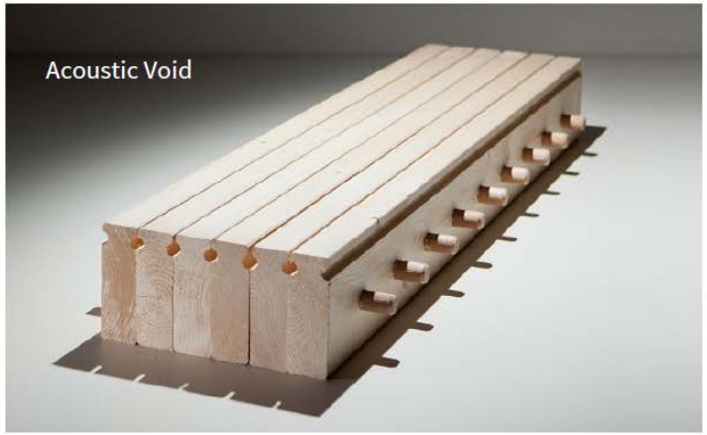
- Similar to NLT
- All wood construction using 7/8" diameter dowels up to 30" long
- Panels can be cut and shaped without fear of tooling striking a nail

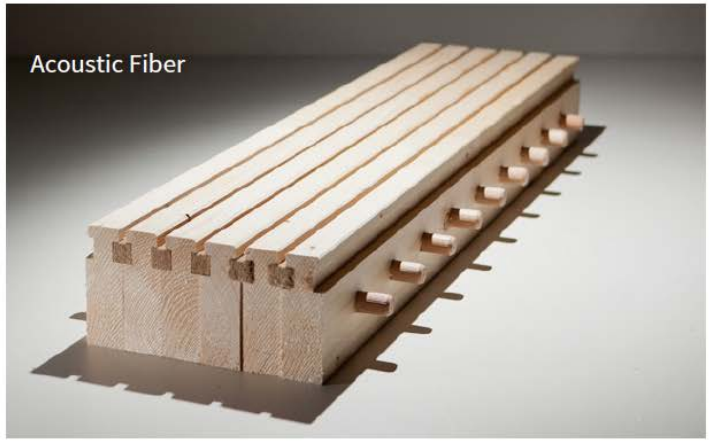


(https://continuingeducation.bnpmedia.com/courses/think-wood/mass-timber-in-north-america/3/)

DLT Profiles







PANEL PROPERTIES

Panel Dimensions	**Length**	Up to 60'
	Width	Up to 14' in any increment
	Thickness (incl. 1/2",sheathing)	3", 4", 6", 7 3/4", 9 3/4", 11 3/4", 13 3/4",
Species & Structural Grade (other species available)	**SPF**	J-Grade, Hiline, No. 2 & Better, 2100f-1.8E MSR
	D.Fir, Hem-Fir	Sel Str, No.1, No. 2 & Better, 2400f-2.0E MSR
Panel Tolerances	+/- 1/8" width, +/- 1/4" length, +/- 1/16" thickness (at time of manufacture)	
Moisture Content	12% +/-3% at time of manufacture	
R-Value	1.25 hr-ft²-F/ Btu (0.22 m² K/W) (per 1" of DLT)	
Specific Heat Capacity	0.38 Btu/lb-F (1.6 kJ/kg-K) @63˚F and 12% MC	
Acoustic Rating	**Raw:** 2x6 DLT achieves **STC 34 and IIC 33** (ASTM E90 and E492 test results) **STC>50 and IIC>50** can be achieved with concrete topping and acoustic mat*	
Fire Performance	Meets heavy timber criteria, can achieve as high as 2hr FRR, or more	
Penetrations/openings	Up to 12" rect/dia without additional reinforcement, larger possible with screw reinforcement	
Transverse Cantilevers, 2-way Spans	Up to 2' weak-axis cantilevers (or 4' spans) are possible with screw reinforcement, longer possible with additional reinforcement	

* Contact StructureCraft Engineering department for acoustic test reports demonstrating DLT performance

Design of DLT

- ESR-4069 allows the use of DLT from StructureCraft Builders, Inc. in US Construction
- ESR report provides values for bending strength (including size factor and repetitive member factor), bending stiffness, shear strength and bearing strength
- No mention is made of the Wet Service factor in ESR-4069 – recommend protection from weather or consultation with manufacturer
- For diaphragm use, consider as laminated decking and must be sheathed with wood structural panels (Section 4.2, SDPWS)
- Use Chapter 16 of NDS to determine fire rating of material

DLT Design – Span Tables

SPF DLT FLOOR SPAN DESIGN GUIDE**

Span (ft)	Floor Live Load (psf)																			
	Single Span / #2 & btr										Single Span / MSR / Sel Str									
	No Concrete Topping					2" Concrete Topping					No Concrete Topping					2" Concrete Topping				
	40	50	70	100	150	40	50	70	100	150	40	50	70	100	150	40	50	70	100	150
10	2x4	2x4	2x4	2x4	2x6	2x4	2x4	2x4	2x4	2x6	2x4	2x4	2x4	2x4	2x4	2x4	2x4	2x4	2x4	2x6
11	2x4	2x4	2x4	2x6	2x6	2x4	2x4	2x6	2x6	2x6	2x4	2x4	2x4	2x4	2x6	2x4	2x4	2x4	2x4	2x6
12	2x4	2x4	2x6	2x6	2x6	2x4	2x6	2x6	2x6	2x6	2x4	2x4	2x4	2x6	2x6	2x4	2x4	2x6	2x6	2x6
13	2x4	2x6	2x6	2x6	2x6	2x6	2x6	2x6	2x6	2x6	2x4	2x4	2x6	2x6	2x6	2x4	2x4	2x6	2x6	2x6
14	2x6	2x6	2x6	2x6	2x6	2x6	2x6	2x6	2x6	2x6	2x4	2x6	2x6	2x6	2x6	2x6	2x6	2x6	2x6	2x6
15	2x6	2x6	2x6	2x6	2x8	2x6	2x6	2x6	2x6	2x8	2x6	2x6	2x6	2x6	2x6	2x6	2x6	2x6	2x6	2x6
16	2x6	2x6	2x6	2x6	2x8	2x6	2x6	2x6	2x8	2x8	2x6	2x6	2x6	2x6	2x8	2x6	2x6	2x6	2x6	2x8
17	2x6	2x6	2x6	2x8	2x8	2x6	2x6	2x8	2x8	2x8	2x6	2x6	2x6	2x6	2x8	2x6	2x6	2x6	2x6	2x8
18	2x6	2x6	2x8	2x8	2x8	2x6	2x6	2x8	2x8	2x8	2x6	2x6	2x6	2x8	2x8	2x6	2x6	2x6	2x8	2x8
19	2x8	2x8	2x8	2x8	2x10	2x8	2x8	2x8	2x8	2x10	2x6	2x6	2x6	2x8	2x8	2x6	2x6	2x8	2x8	2x8
20	2x8	2x8	2x8	2x8	2x10	2x8	2x8	2x8	2x8	2x10	2x6	2x6	2x8	2x8	2x8	2x6	2x6	2x8	2x8	2x8
22	2x8	2x8	2x8	2x10	2x10	2x8	2x8	2x8	2x10	2x10	2x8	2x8	2x8	2x8	2x10	2x8	2x8	2x8	2x8	2x10
24	2x10	2x10	2x10	2x10	2x10	2x10	2x10	2x10	2x10	2x12	2x8	2x8	2x8	2x10	2x10	2x8	2x8	2x8	2x10	2x10
26	2x10	2x10	2x10	2x10	2x12	2x10	2x10	2x10	2x10	2x12	2x10	2x10	2x10	2x10	2x10	2x10	2x10	2x10	2x10	2x12
28	2x12	2x12	2x12	2x12	2x12	2x12	2x12	2x12	2x12	2x12	2x10	2x10	2x10	2x10	2x12	2x10	2x10	2x10	2x10	2x12
30	2x12	2x12	2x12	2x12		2x12	2x12	2x12	2x12		2x12	2x12	2x12	2x12	2x12	2x12	2x12	2x12	2x12	2x12
32											2x12	2x12	2x12	2x12		2x12	2x12	2x12	2x12	

DLT Design - Walls

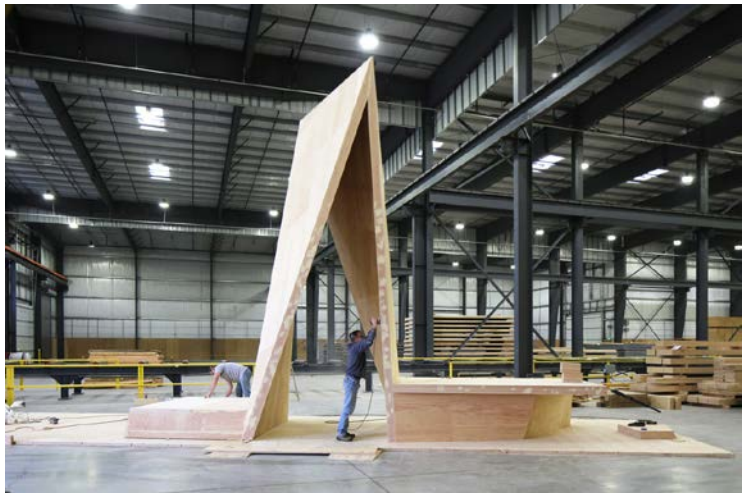
SPF DLT WALL SPAN DESIGN GUIDE**

DLT Series	SPF - DLT Wall Panel Axial Capacity									
	2x4 89mm #2&btr	2x4 89mm 2100f-1.8E	2x6 140mm #2&btr	2x6 140mm 2100f-1.8E	2x8 184mm #2&btr	2x8 184mm 1950f-1.7E	2x10 235mm #2&btr	2x10 235mm Sel Str	2x12 286mm #2&btr	2x12 286mm Sel Str
H (ft)	P_r (kip/ft)									
6	37	62	84	142	117	195	151	190	183	230
8	23	37	67	112	103	169	139	174	171	215
10	14	22	51	83	87	141	126	157	160	200
12	9	14	38	61	72	115	112	138	148	184
14	6	9	28	45	58	92	98	120	135	167
16			21	33	47	73	84	102	122	150
18			15	25	37	57	71	86	108	133
20			12	19	30	45	60	72	96	116
22			9	15	24	36	51	60	84	101
24			7	11	19	29	43	51	73	88
26			6	9	16	24	36	42	64	76
28					13	20	30	36	56	66
30					11	16	26	30	48	57
32					9	14	22	26	42	50
34					8	11	19	22	37	43

MPP (Mass Plywood Panel)

- A very thick plywood panel
- Proprietary Panel, Currently Produced by Freres Lumber Co.
- Listed on APA website with CLT products (complies with PRG-320)
- Intent is to use similar to CLT (a two-way panel)
- This is plywood
  - According to NDS, you cannot apply fasteners into the ends of plywood

(https://www.homag.com/en/news-events/case-studies/detail/mpp-new-innovative-plywood-panel-product)



(https://leverarchitecture.com/research/mass_plywood_fabrication_and_assembly)

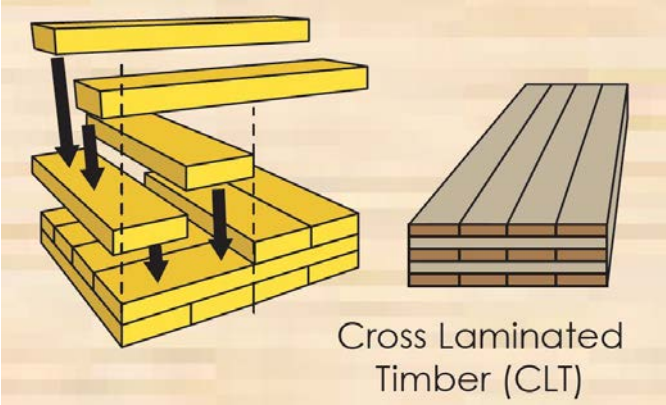
CLT – **Cross**-Laminated Timber

- Constructed Like Plywood
- Layers are Oriented 90 degrees to Previous Layer
- Layers can be from 5/8″ to 2″, typically 1-3/8″ (1.5″ planed)
- Odd Number Layers From 3 to 11 (4.5″ to 20″ thick)
- Lumber Used is Typically Spruce or Douglas fir
- Manufacturing Standard Approves Softwoods for Use

(https://www.thinkwood.com/mass-timber/clt)

CLT – Cross-**Laminated** Timber

- Firmly affixed with adhesive
- Adhesives include polyurethane, melamine urea formaldehyde, phenol formaldehyde
- Pressures vary but can be very large, requiring expensive press
- Cold press technology is used



(https://metro-acoustics.com/2019/08/21/august-2019-newsletter-cross-laminated-timber-acoustics/)

CLT – Cross Laminated **Timber**

- The final product is a large panel
- "A giant piece of plywood!"
- Use is different than light-frame materials
- Use is similar to pre-cast concrete panels

Source Documents for CLT

- ANSI/APA PRG-320-2019 *Standard for Performance-Rated Cross-Laminated Timber*
  - Requirements and Test Methods for Qualification of CLT panels
  - Design Values for CLT Grades
- Available from APA website (www.apawood.org)
- NDS provisions only apply to CLT rated using ANSI/APA PRG-320
- More information on producers who have been authorized for producing mass timber for use in United States

What Does PRG-320 Tell Us?

- V, E, S Grades
  - V = Visual Grade Lumber used in face
  - E = Mechanical Graded Lumber used in face
  - S = Structural Composite Lumber (SCL) used in face
- Grades are based upon lumber species
- Typical to use No. 3 lumber in cross-layers
- Typical lamination thickness = 1.375" (2x with 1/8" planed off faces)
- Panel thickness not more than 20 inches
- Currently only softwood lumber considered for CLT manufacture
- Lumber moisture content 12 ± 3%
- Final panel moisture content 8 ± 3%

CLT Grades

Grade	Face Layer (Major)	Cross Layer (Minor)
E1	1950f-1.7E Spruce-Pine-Fir	No. 3 Spruce-Pine-Fir
E2	1650f-1.5E Douglas Fir-Larch	No. 3 Douglas Fir-Larch
E3	1200f-1.2E Eastern Softwoods, Northern Species, or Western Woods	No. 3 Eastern Softwoods, Northern Species, or Western Woods
E4	1950f-1.7E Southern Pine	No. 3 Southern Pine
E5	1650f-1.5E Hem-Fir	No. 3 Hem-Fir
V1	No. 2 Douglas Fir-Larch	No. 3 Douglas Fir-Larch
V1(N)	No. 2 Douglas Fir-Larch (North)	No. 3 Douglas Fir-Larch (North)
V2	No. 1/2 Spruce-Pine-Fire	No. 3 Spruc-Pine-Fir
V3	No. 2 Southern Pine	No. 3 Southern Pine
V4	No. 2 Spruce-Pine-Fir South	No. 3 Spruce-Pine-Fir South
V5	No. 2 Hem-Fir	No. 3 Hem-Fir
S1	2250f-1.5E Laminated Veneer Lumber (LVL)	
S2	1900f-1.3E Laminated Strand Lumber (LSL)	
S3	1750f-1.3E Oriented Strand Lumber (OSL)	

Mechanical Properties of Grades

TABLE A2 (continued)

ASD REFERENCE DESIGN VALUES[a] FOR BASIC CLT GRADES AND LAYUPS (FOR USE IN THE U.S.)

		Lamination Thickness (in.) in CLT Layup							Major Strength Direction				Minor Strength Direction			
CLT Grade	t_p (in.)	=	⊥	=	⊥	=	⊥	=	$(F_bS)_{eff,f,0}$ (lbf-ft/ft of width)	$(EI)_{eff,f,0}$ (10^6 lbf-in.²/ft of width)	$(GA)_{eff,f,0}$ (10^6 lbf/ft of width)	$V_{s,0}$ (lbf/ft of width)	$(F_bS)_{eff,f,90}$ (lbf-ft/ft of width)	$(EI)_{eff,f,90}$ (10^6 lbf-in.²/ft of width)	$(GA)_{eff,f,90}$ (10^6 lbf/ft of width)	$V_{s,90}$ (lbf/ft of width)
V3	4 1/8	1 3/8	1 3/8	1 3/8					1,740	95	0.49	1,820	140	3.4	0.52	605
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,000	363	0.98	3,025	1,230	88	1.0	1,820
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	7,100	899	1.5	4,225	2,825	338	1.6	3,025
V4	4 1/8	1 3/8	1 3/8	1 3/8					1,800	74	0.38	1,490	140	2.6	0.41	495
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,150	285	0.76	2,480	1,230	68	0.82	1,490
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	7,325	706	1.1	3,475	2,825	260	1.2	2,480
V5	4 1/8	1 3/8	1 3/8	1 3/8					1,980	88	0.45	1,650	160	3.1	0.48	550
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,550	337	0.91	2,750	1,370	81	0.97	1,650
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	8,025	835	1.4	3,850	3,150	312	1.5	2,750
S1	4 1/2	1 1/2	1 1/2	1 1/2					6,225	132	0.61	1,440	845	5.1	0.61	480
	7 1/2	1 1/2	1 1/2	1 1/2	1 1/2	1 1/2			14,325	506	1.2	2,400	7,325	132	1.2	1,440
	10 1/2	1 1/2	1 1/2	1 1/2	1 1/2	1 1/2	1 1/2	1 1/2	25,325	1,252	1.8	3,350	16,850	506	1.8	2,400
S2	4 1/2	1 1/2	1 1/2	1 1/2					5,250	114	0.53	1,800	715	4.4	0.53	600
	7 1/2	1 1/2	1 1/2	1 1/2	1 1/2	1 1/2			12,100	438	1.1	3,000	6,175	114	1.1	1,800
	10 1/2	1 1/2	1 1/2	1 1/2	1 1/2	1 1/2	1 1/2	1 1/2	21,400	1,085	1.6	4,200	14,225	438	1.6	3,000
S3	4 1/2	1 1/2	1 1/2	1 1/2					4,850	114	0.53	1,260	655	4.4	0.53	420
	7 1/2	1 1/2	1 1/2	1 1/2	1 1/2	1 1/2			11,150	438	1.1	2,100	5,700	114	1.1	1,260
	10 1/2	1 1/2	1 1/2	1 1/2	1 1/2	1 1/2	1 1/2	1 1/2	19,700	1,085	1.6	2,950	13,000	438	1.6	2,100

For SI: 1 in. = 25.4 mm; 1 ft = 304.8 mm; 1 lbf = 4.448 N

a. This table represents the basic CLT grades and layups. Custom CLT grades and layups that are not listed in this table shall be permitted in accordance with 7.1.2.

Mechanical Properties

$(F_bS)_{eff,f,0}$ (lbf-ft/ ft of width)	$(EI)_{eff,f,0}$ (10^6 lbf-in.^{2}/ft of width)	$(GA)_{eff,f,0}$ (10^6 lbf/ ft of width)	$V_{s,0}$ (lbf/ft of width)

- Mechanical properties given are composite properties with the subscript 'eff' for 'effective'
- Shear Analogy Model was used to account for cross-lamination strength / stiffness in panel
- GA property = shear stiffness
- CLTs have a large portion of shear deflection and the shear stiffness must be accounted for
- Also, notice properties are given on a 'per foot width' basis

Mass Timber Design

- Column / Wall Design
- Floor design Including Vibration
- Connection Design
- Diaphragm Strength
- Shearwall Strength

Column / Wall Design

- ANSI/APA PRG-320 gives compression properties for the major / minor axes in CLT
- Compression strength of CLT can conservatively be considered as the compression strength of parallel laminations to load
- Lateral Buckling Factor C_P should be considered for applicable cases in the panel face (minor axis)

Floor Design

- CLT sections can be designed in a one-way analysis or two-way analysis
- Design Values
  - Bending
  - Shear
  - Deflection (Including both bending and shear deflection terms)
  - Bearing
- Pay attention to end support conditions (may be multiple span)

Vibration of Floors

- Timber Design Guide 2019-14 "Mass Timber Floor Systems – Vibration Serviceability Considerations" by Lucas Epp (TFEC)
- Vibration issues can occur in CLT floors due to low mass
- CLT Handbook provides recommendations for maximum spans for panel thicknesses
  - Assuming panels are supported on rigid walls with no concrete topping

Panel	Maximum Span
4-1/8" thick (3-ply) CLT or 3-1/2" NLT/DLT/GLT	11ft to 12ft
6-7/8" thick (5-ply) CLT or 5-1/2" NLT/DLT/GLT	15ft to 17ft
9-5/8" thick (7-ply) CLT or 7-1/4" NLT/DLT/GLT	19ft to 21ft

Vibration of Floors With Toppings

- To reduce natural frequency and increase modal mass to prevent footfall excitation, non-composite concrete or gypum toppings used
- 3 approaches to vibration design
  - Simplified formulas presented in CLT Handbook
    - Suggest reduce span by 10% for floor topping
    - Values are considered overly conservative
  - Modal Response Analysis
  - Time History Analysis

  } Considered More Accurate Methods

- Modal damping of CLTs in in the range of 2.5% to 3.5%

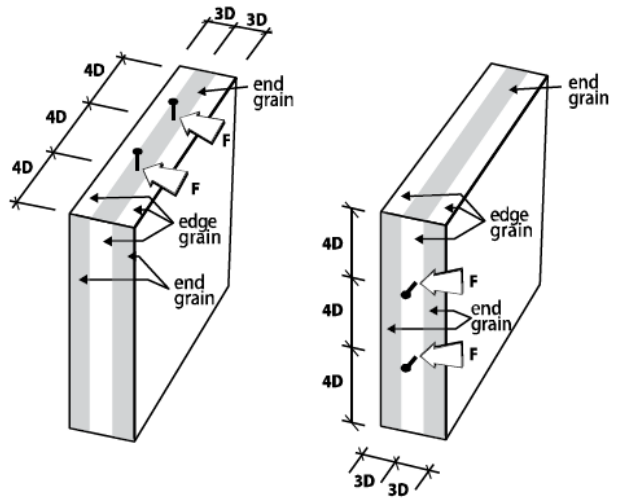
CLT Connections – Narrow Face of CLT

- Table 12.5.1G gives provisions for end, edge, and fastener spacing

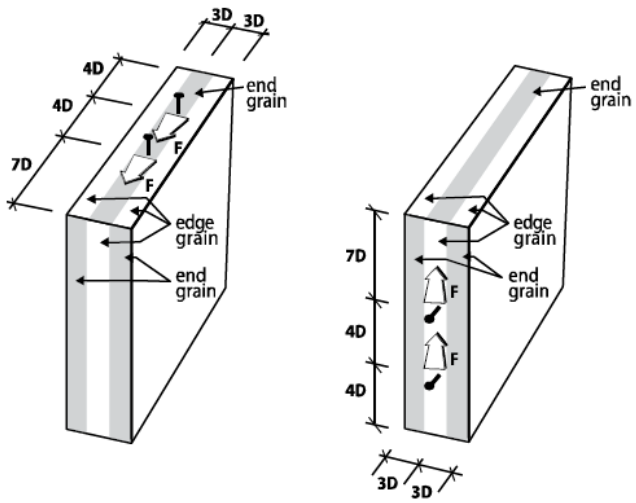
Table 12.5.1G End Distance, Edge Distance and Fastener Spacing Requirements in Narrow Edge of Cross-Laminated Timber (see Figure 12I)

Direction of Loading	Minimum End Distance	Minimum Edge Distance	Minimum Spacing for Fasteners in a Row
Perpendicular to Plane of CLT	4D	3D	4D
Parallel to Plane of CLT, Compression: (fastener bearing away from member end)	4D		
Parallel to Plane of CLT, Tension: (fastener bearing toward member end)	7D		

Figure 12I End Distance, Edge Distance and Fastener Spacing Requirements in Narrow Edge of Cross-Laminated Timber



Direction of loading perpendicular to the plane of CLT



Direction of loading parallel to the plane of CLT

CLT Connections – Wide Face of CLT

- Fastener is traveling through different wood layers oriented differently
- 12.3.3.5 Dowel bearing strengths, F_e, for dowel-type fasteners installed into the panel face of cross-laminated timber shall be based on the direction of loading with respect to the grain orientation of the cross-laminated timber ply at the shear plane (NDS, p. 84)
- 12.3.5.2 For cross-laminated timber where the direction of loading relative to the grain orientation at the shear plane is parallel to grain, the dowel bearing length in the perpendicular plies shall be reduced by multiplying the bearing length of those plies by the ratio of dowel bearing strength perpendicular to grain to dowel bearing strength parallel to grain ($F_{e\ perp}$ / $F_{e\ parallel}$) (NDS, p. 84)

CLT Connections – Wide Face of CLT

- $l_{m(adj)} = \left[l_{\parallel} + l_{\perp} \frac{F_{e(perpendicular)}}{F_{e(parallel)}} \right]$ (9)
- Where,
- $l_{m(adj)}$ = effective bearing length adjustment for CLTs
- $l_{\parallel}$ = total fastener bearing length in parallel layer(s)
- $l_{\perp}$ = total fastener bearing length in perpendicular layer(s)

- Alternate Method: Modify F_e , Keep fastener length the same
- $F_{e(proposed)} = \frac{\sum_{i=1}^{n-1} F_{e(i)} t_i + F_{e(n)} \left(p - \sum_{i=1}^{n-1} t_i \right)}{p}$

CLT Lateral Design Methods

- CLT lateral design methods are not settled yet
- Current methods are YOUR best mechanics-based rationalization
- CLT manufacturers may be able to provide design advice
- The following observations are a collection of documents and ideas meant to help

CLT Diaphragm Panels

- Timber Design Guide 2020-19 "Cross-Laminated Timber (CLT) Diaphragms" by Jim DeStefano and Rick Way, TFEC
- Currently little guidance on diaphragm design
- Testing of CLTs diaphragms has yet to be attempted / in-process, but is very difficult
- Consider CLT floors and roofs to act as rigid diaphragms
  - Distribution of lateral loads is based on relative stiffness of support elements
- Aspect Ratio (L/W)
  - L/W ≤ 3:1 for non-composite concrete topping (2-1/2" minimum)
  - L/W ≤ 2:1 if there is no concrete topping
  - If 3:1 < L/W ≤ 4:1 diaphragm can be modeled as semi-rigid (suggested approach – check both rigid and flexible designs)

R-Factor

- One of the first difficulties of CLT lateral design is the lack of a decided-upon R-factor for seismic loads
- CLT is not recognized in ASCE 7 Table 12.2-1
- Options
  - Performance-based design procedure per ASCE 7
  - Demonstrating equivalence to an existing ASCE 7 system
  - ASCE 7-16, FEMA P695, FEMA P795 Quantification of Building Seismic Performance Factors
  - Use a prescribed system from ASCE 7 as the lateral resistance system

CLT Diaphragm Design

- DeStefano and Way (2020) use the following formula to calculate the in-plane shear strength (lb/ft of width) of CLT panels
- V (in-plane shear strength) = $12*t*F_v*C_D/1.5$
  - t = thickness of cross-plies (1 cross-ply for 3-layer CLT, etc)
  - $C_D = 1.6$
- The diaphragm panel strength is also dependent upon the shear strength of the panel connections (typ. splines) to transfer shear
- Connections are important to check as well and may limit diaphragm strength

CLT Shearwalls

- More research on CLT shearwalls vs. diaphragms
- Most work has been on specific panel types and damping systems
- Many shearwall studies could not cause failure in the CLT panel, but rather the connection systems of the CLT to the foundation
- Many shearwall design methods (segmented, perforated, force transfer at opening) have been found to be conservative in force estimation

Summary

- Engineered Wood Products allow us to create a wider range of buildings compared to solid-sawn lumber
- The use of wood composites helps to reduce product variability and modify the mechanical properties of the material
- Engineered Wood Products have distinct advantages and disadvantages in construction
- Mass Timber and CLT are emerging materials which allow us to create event taller wood buildings

Where To Learn More

- WoodWorks, www.woodworks.org
  - Resource for non-residential, wood construction
  - Case studies, research library
  - Host continuing education seminars across country
  - Consultants able to advise you on non-residential wood use
- American Wood Council, www.awc.org
  - Resources for wood design literature
  - Offers continuing education classes
  - Technical question helpline
- APA-EWS, www.apawood.org
  - Main trade association for Engineered Wood Products
  - Access to standards, example calculations and research
  - Listing of manufacturers
- ThinkWood, www.thinkwood.com/
- Timber Frame Engineering Council, www.tfguild.org/timber-frame-engineering

Thanks for your attendance!

- Questions?
- dhindman@vt.edu